VOLUME 6 AUGUST, 1918 NUMBER 4

PROCEEDINGS
of
The Institute of Radio Engineers

EDITED BY
ALFRED N. GOLDSMITH, Ph.D

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS
THE COLLEGE OF THE CITY OF NEW YORK

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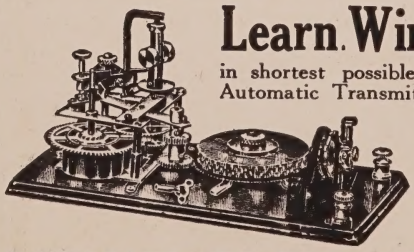

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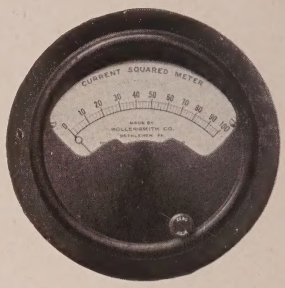

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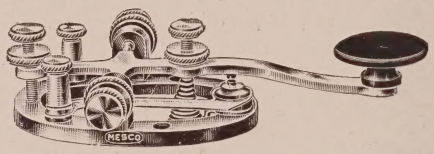

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The Institute of Radio Engineers
announces with regret the deaths of

Edgar H. Fessenden

and

Eugene M. Murray

Mr. Fessenden was born in Brooklyn, N. Y., and trained in the public schools of that City and in the Brooklyn Commercial High School. After considerable experience as a radio amateur, he passed thru the Marconi School for Operators, thereafter becoming a professional steamship operator.

Prior to the war, he joined the First Battalion of the New York Naval Reserve. At the entrance of our country into the war, he entered the United States Navy as third-class Radio Electrician. While in charge of the radio service of one of the United States Naval vessels, he acted as instructor and passed the examinations for Chief Radio Electrician. An illness contracted in service caused his death on March 15, 1918.

Mr. Murray was an Associate member of The Institute of Radio Engineers and a skilled radio worker. He was formerly an Installation Engineer of the Marconi Wireless Telegraph Company of America. He was commissioned an Ensign in the United States Naval Reserve Force, and called to active duty on April 6, 1917. While in service, he received injuries resulting in his death on May 30, 1918. His residence was at Haverford, Pennsylvania.

RADIO COMMUNICATION WITH MOVING TRAINS*

By

Dr. Frederick H. Millener

(Experimental Engineer, Union Pacific Railroad, Omaha, Nebraska)

The following paper is a brief resumé of the more or less laborious and comprehensive research work undertaken by the writer for the Union Pacific Railroad Company during the period from 1906 to 1916, inclusive. The bare details of this work form a fairly consecutive study of the arts of radio telegraphy and telephony as they are generally known today.

The Coherer and Other Detectors for Radio Signals

In October, 1906, the management of one of the great railroads of the country requested me to devote my time to finding a method of signalling the cab of a locomotive or communicating with a train without interfering in any manner with the right of way or placing any obstruction along it. By this is meant that obstructions which could or would interfere with the work of a snow plow or with the present equipment of the railroad were excluded. For the purpose of experiment, an electric storage battery truck made by the Westinghouse Manufacturing Company, weighing 5,500 pounds (2,500 kg.) with the batteries in place, made of steel, and running on the Shop Yards narrow gauge track at Omaha was utilized. This car was equipped with an antenna, and on it all my purely experimental work was carried out, in such a way as not to interfere with the operating officials or to become in any way a menace to the right of way. Nothing has ever been suggested as an addition to or change in the right of way that has not actually worked, in a very practical manner on this machine.

The first great difficulty which was experienced was to secure a good ground. The axles were packed and ran in vaseline. The only way we could secure any effective radio control on the car was by having a steel brush forcibly pressed into contact with the rail. This was a nuisance, and would not work over

* Received by the Editor, November 17, 1917. Presented before The Institute of Radio Engineers, New York, December 5, 1917.

ice and snow. It was found that if the ground wire came into contact with the steel frame of the car (this frame acting as a counterpoise), no further trouble was experienced in receiving the impulse or wave train which caused the relay to work.

An antenna was placed on the Boiler Shop, near the laboratory, 140 feet (43 m.) above the ground, having a natural wave length of about 500 meters. This electric truck has been exceedingly valuable for experimental purposes because it had available a source of 186-volt direct current, and sufficient

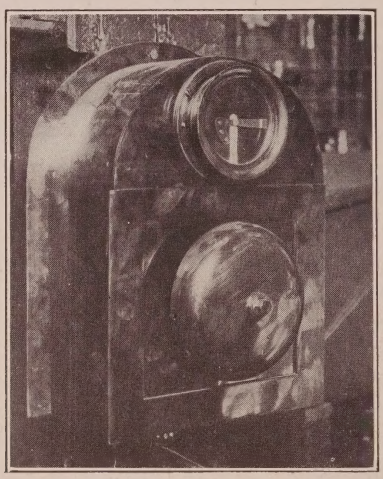

FIGURE 1—Signal Box, with Arm at "Block" ("Danger"); bell ringing

power. Our object at this time was to operate a block signal in the cab of a locomotive from a block signal tower, the idea being that when the arm on the tower went to "Danger" it would cut in storage batteries connected to an induction coil, a tuned circuit, and other equipment necessary to radiate electromagnetic waves over a short distance, such waves to be received by the antenna on the approaching locomotive and to cause the device in the cab to set a like arm at "Danger." Figure 1, illustrating this machine is shown herewith.

However, on a railroad, a danger signal must operate at least 100,000 times in succession without a failure, and must not be operated by any other means than the means intended. As the lighting of an arc light, an atmospheric disturbance, or

casual spark will sometimes cause this signal to operate, and as the best coherer or valve detector which we were able to secure actually, or to learn of, would not last for anything like 100,000 operations without a failure, work was discontinued on the mechanical radio cab signal. Altho no *mechanical* difficulty which could not be overcome had presented itself, a physical one had; namely, that the device was not sufficiently reliable tho it was possible to see its value easily during sleet storms, rain storms, and similar disturbances. This, of course, was one of the earlier reasons why the coherer was displaced in radio telegraphy, and the telephone and detector substituted. The first radio equipment utilized, together with the interior of the place that was then our laboratory is shown in Figure 2.

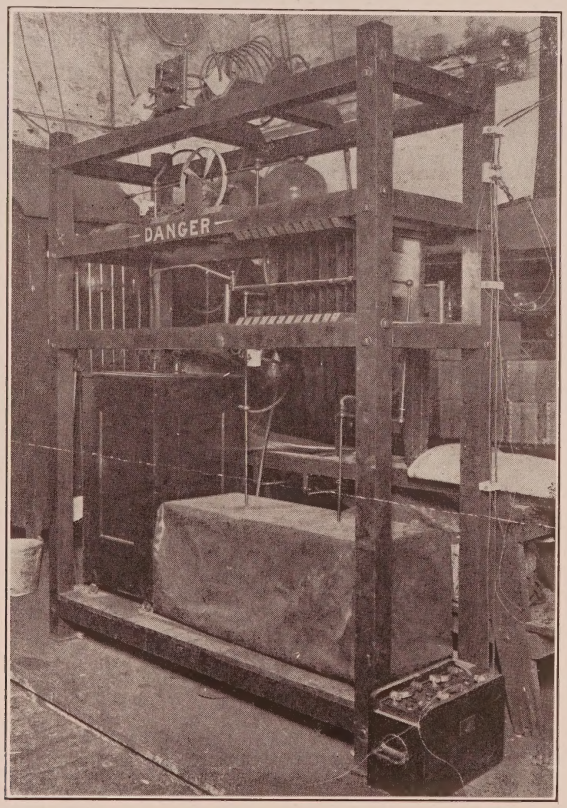

FIGURE 2—First Radio Laboratory at Union Pacific Railroad Shops

There were numerous difficulties in the way of successful experimentation. Standard instruments were exceedingly costly and rather unreliable. The patent situation was such that we could not tell whom one would ultimately have to pay for the use of any device nor the amount to be paid. There were many "systems," and many of the patents covering them were possible infringement of patents in this country or abroad. Quite regularly some corporation would threaten our Law Department with suits for using any form of radio equipment but theirs.

In developing this cab signal, it was necessary to be absolutely certain that it would work the mechanism on the locomotive, and to determine how often and how well it would work. The electric relay was caused to operate the driving mechanism of the electric truck at four speeds ahead, four speeds back, and to ring a bell. This was done of course, by means of the coherer, a four-ohm track relay, such as used by the Signal Department and a portion of the Independent Telephone Company's jenny and a large relay. The complete apparatus is shown in Figure 3.

FIGURE 3—Radio Controlled Truck Under Test

All of these instruments were, of course, hand made, by myself and my friends and assistants in the Shops.

We found, that if we could control this car in this manner, we might be able to make the block signal work in the cab of

the locomotive, and a picture of the locomotive equipped with such a cab signal is given in Figure 4.

As the result of the application of radio to a car, which was believed to be the first piece of heavy machinery ever so con-

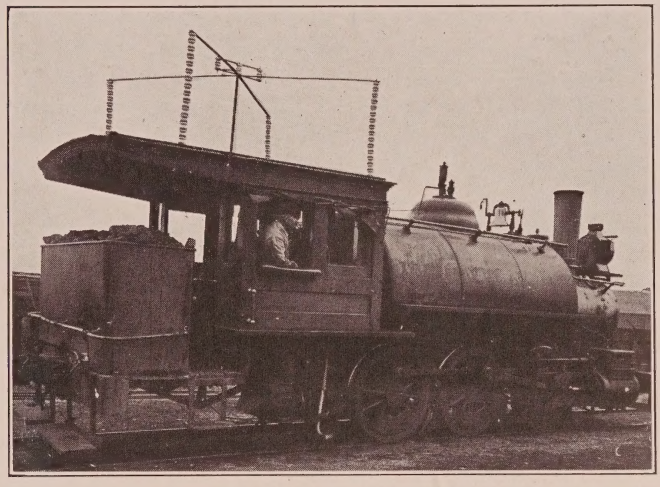

FIGURE 4—Engine Equipped with Radio Controlled Signal

trolled, our work was broadened. We were given a better laboratory and more facilities and were requested to devote our whole time to the work.

RADIO TELEGRAPHY—SYSTEM AND STATIONS

The Union Pacific Railroad has always been considered more or less a military road, it having the lowest grade of any road over the mountains and its work has been essentially that of a transcontinental railroad. Those people of the East, who have not been in the West, can scarcely realize that it is a country of magnificent distances. Such a country develops its population on the same broad lines. For miles and miles there are no trees, homes, or habitations. In winter it is not an uncommon sight to see along the track a line of telegraph poles and wires which have been put out of commission by ice, heavy wind or sleet storms and floods. So it seems that in such a country as this, there might be an opportunity to develop radio telegraphy. It was decided that some stations of a complete sys-

tem in this region were to be merely for receiving and some to be for both sending and receiving.

We were therefore directed to prepare plans and specifications for such a system, and if possible to make it flexible enough to telegraph to a moving train. It was thought that stations could be erected at certain cities and then outfit cars fitted up with one or two kilowatt sets, which were to be kept at division points. These cars were to contain a mast, which could be raised thru the roof of a car when on a siding, and a temporary station installed at either side of a wire break; communication being thus established until such time as the line men could complete their work. The one thought which was strictly impressed upon our minds at all times was that this apparatus must be cheap and simple, so that local men could be taught its use and operation to avoid the necessity of having experts, and that its whole value would be entirely dependent on this.

For 600 miles (1,000 km.) west of Omaha the country is comparatively level and straight. The elevation at Omaha is 1,200 feet (350 m.), gradually rising until an elevation of 8,000 feet (2,500 m.) is reached at the summit of Sherman Hill, Wyoming. In planning for radio telegraph stations, this elevation must be taken into consideration. Another thing which needs very close attention, and which causes very serious conditions is *static electricity.* In summer, the static electricity between Sidney, Nebraska; Cheyenne, Wyoming and Sherman Hill, Wyoming, causes all manner of disturbances with block signals, burning them out, and occasionally putting the wire telegraph out of commission. Very little was *generally* known about the arc method of Poulsen and about the experimental work that was then being done on the 500-cycle spark work of Marconi and others, and the rotary synchronous spark gap of Fessenden. But the least expensive method and the one which was decided upon was the 60-cycle closed core transformer, the rotary spark gap, and the tinfoil condenser transmitter, which was then used by the Telefunken Company. These stations were to be of sufficient power to be heard night or day, summer or winter, at least as far as the next sending station. We expected the station at Cheyenne to work as far east as Omaha and an equal distance the other side of the mountains. The other sending stations were to be at Sidney, Grand Island, North Platte, Green River, and Omaha. Experiment taught that we would be able to hear the high pitched note of these stations above the strays, and later developments conclusively

proved this to be true. We were then requested to work out a system of radio telegraph and radio telephony, which could be applied to railroad uses where it would have value in protecting human life.

Figure 5 is a detailed drawing of the house for the radio station as it appeared when ready for use. These houses were 14 feet (4 m.) front and 16 feet (5 m.) deep, and contained two rooms. The rear room was the power room and contained the heavy machinery, cupboards, and other equipment. The front room contained the sending and receiving instruments and the operator's table. The wires were brought in carefully insulated thru a concrete duct under the floor. This arrangement is shown in Figure 5.

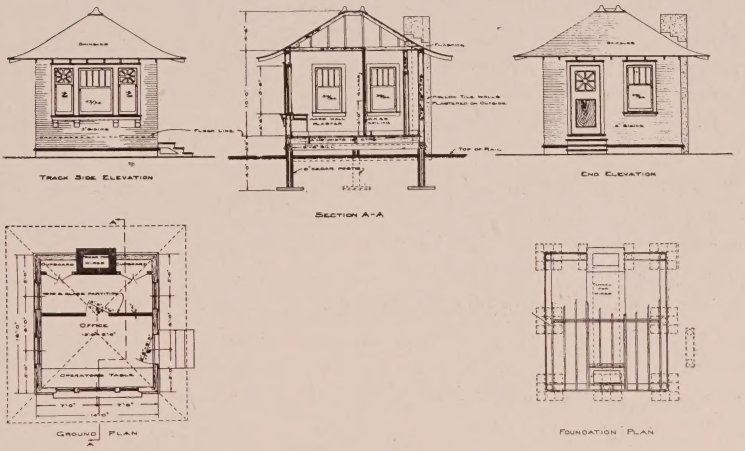

Figure 5—Railroad Radio Station

Antennas

In railroad work, it is absolutely necessary to have the antennas close and compact. It seems that there is no doubt that the flat top antenna is the best and most practical antenna for every day use, either for railroads or in the field. (But the initial expense in erecting the same under the best working conditions is sometimes prohibitive.) In the first installation of the railroad radio telegraph, it was absolutely necessary not to complicate matters. The antennas had to be simple and easy to repair. We were obliged to endeavor to utilize men in the employ of the railroad and not to import experts.

It is, then, desirable to have a flat top antenna at stations, parallel to the track, and supported by two self-sustaining towers, the height of which should be at least 180 to 210 feet (55 to 65 m.) and which should be constructed to stand a wind stress of 90 miles per hour (150 km. per hour). There were, however, places where we could only have one mast. Examples of both kinds with drawings are given in Figures 6, 7, and 8.

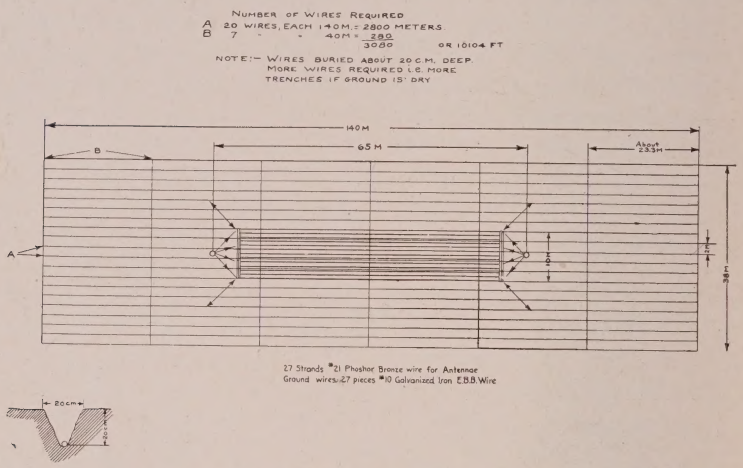
NUMBER OF WIRES REQUIRED
A 20 WIRES, EACH 140 M. = 2800 METERS
B 7 " " 40 M. = 280
3080
OR 10104 FT
NOTE:— WIRES BURIED ABOUT 20 C.M. DEEP.
MORE WIRES REQUIRED I.E. MORE
TRENCHES IF GROUND IS DRY
140 M
65 M
B
A
27 Strands #21 Phosfor Bronze wire for Antennae
Ground wires 27 pieces #10 Galvanized Iron E.B.B. Wire
20cm
10cm

FIGURE 6—Flat Top Antenna and Ground

It was necessary that the antenna be so arranged that it could easily be freed from snow and ice. The umbrella antenna requires too many guy wires and at the critical moment frequently fails on account of snow and ice. It is also difficult to repair in the yards and stations, and it takes up too much space. The single mast antenna which is shown below was designed for this purpose, and has porcelain insulators at the top. The units are made in such a manner as to loosen the snow and ice.* A specially constructed ground or counterpoise is used. Figure 9 represents the mast and tower with the house at the base; and the arrangement of the antennas. Figure 10, is a detailed drawing of the insulators at the top of the mast, and of a detail of the inner ring of the insulator and the ring around the mast. Figure 11 represents a detail of the weaving

* U. S. Patent Number 1,206,353; filed January 19, 1912.

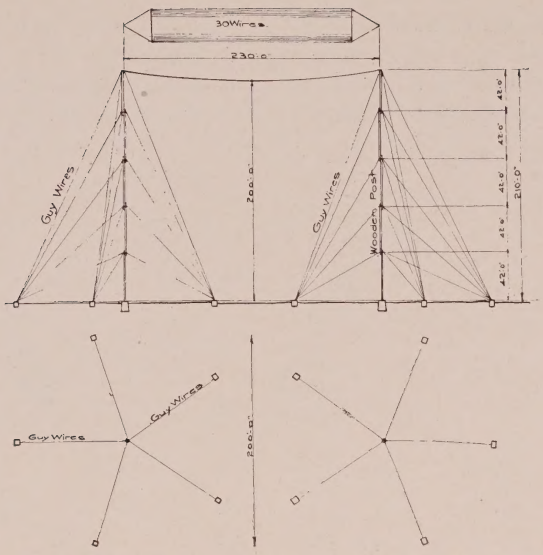

FIGURE 7—Flat Top Antenna, Wooden Masts

antenna for breaking off ice or clinging snow, and also a counterpoise utilizing the unbonded sections of track in the yard and

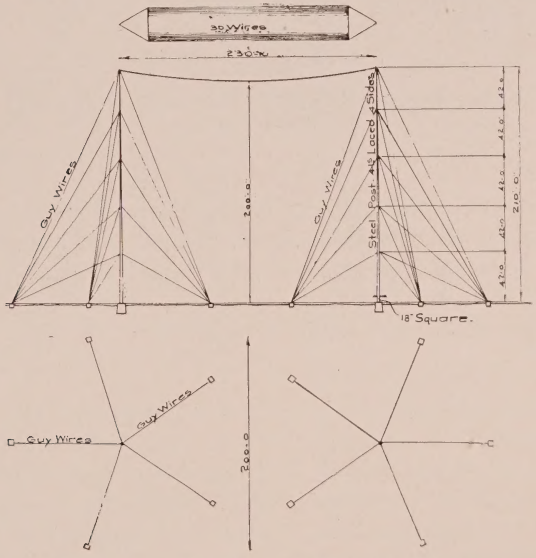

FIGURE 8—Flat Top Antenna, Steel Masts

such other material as might run on the track to increase the capacity.

In the west, a good ground is hard to secure on account of the light sandy soil which is at times very dry. The ground

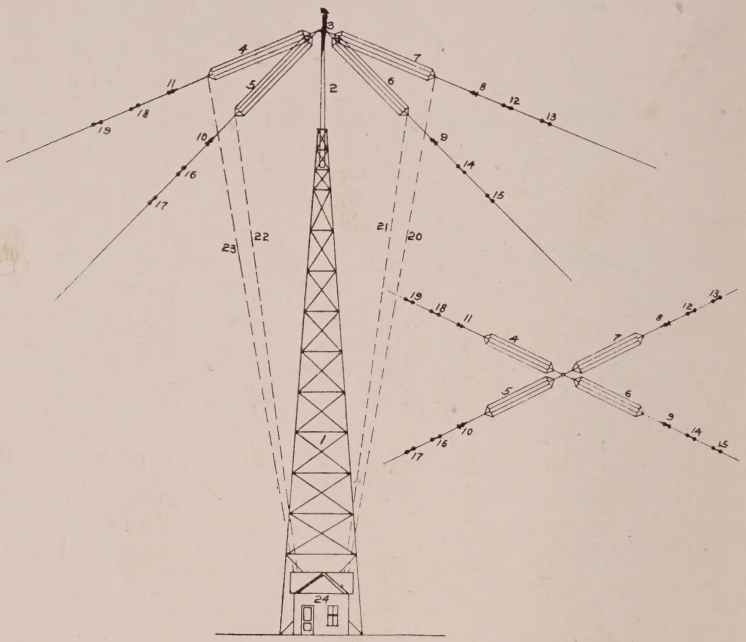

FIGURE 5—Structure of Special Umbrella Antenna for Railroad Radio Stations

or counterpoise of Figure 6 was intended to be located at Cheyenne, in the park adjacent to the railroad and belonging to the depot. The various styles of mast construction are shown in Figures 7 and 8. These were intended to be used in the installations.

TRANSMITTING APPARATUS

It was planned to have radio stations at Ogden, Utah; Green River, Wyoming; Cheyenne, Wyoming; North Platte, Nebraska; Grand Island, Nebraska; and the plant at Omaha was already in existence. There was thus covered the entire system west of Omaha. Where one support was already in place, the flat top antenna was to be used. Where both supports

would have had to be built, an umbrella antenna was planned. Where the antenna was of the flat top type, we used yards or spreaders made up of 30 feet (9 m.) of 4-inch (10 cm.) wrought iron pipe. These will space and carry twelve copper wires,

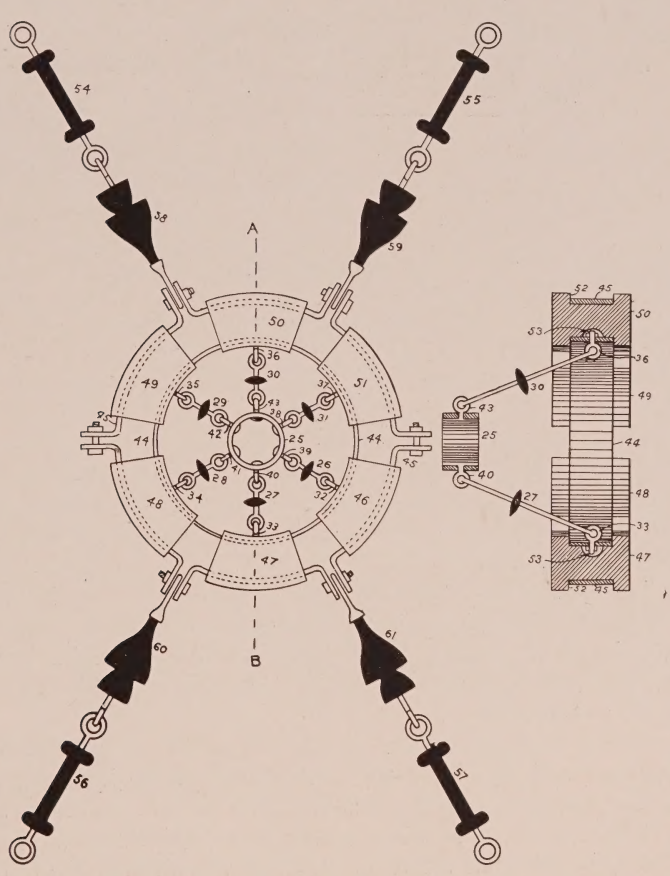

FIGURE 10—Top-of-Mast Fittings of Special Umbrella Antenna

25 feet (75 cm.) apart, 700 feet (200 m.) long. The spreader in question is illustrated in Figure 12. The umbrella masts have been previously explained.

The placing of a network of wires in the ground at the parks insured a perfect ground or counterposie connection at all times, wet or dry, and if more connections were needed, the unbonded

yard tracks would be used without interfering with the traffic or signals. The railroad tracks are all connected by wires at the end of each rail for the block signals. This is called bonding.

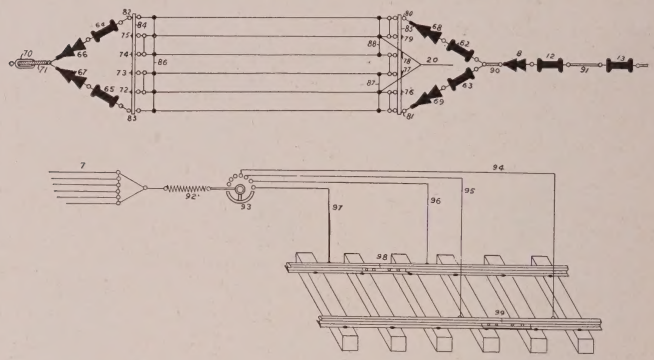

FIGURE 11—Spreader Structure of Antenna; Counterpoise Rail Ground

It was found that placing the masts parallel with the tracks and close to them was of great assistance in working east or west and in transmitting over the mountains, the rails seeming to assist transmission.

The station at Green River was to have been a ten-kilowatt sending station, the station at Cheyenne a five-kilowatt, and the stations at Ogden, North Platte, and Grand Island were each to have been two kilowatts. The wave lengths were to be 600 to 800 meters.

The altitude at Green River, Wyoming, was 6,082 feet (1850 m.) and at Cheyenne, 6,068 feet, and the highest point on the railroad was at 8,000 feet (2,500 m.). Taking into consideration the atmospheric conditions surrounding the mountains (especially on Sherman Hill), it was desired that these two stations should radiate directly over the mountains to Omaha. In order to be sure to secure this result, the ten-kilowatt station at Green River and the five-kilowatt station at Cheyenne were chosen.

From experiments conducted and observations taken, the possibilities are that both of these stations would be read as far as Omaha without any difficulty since a high pitched spark note was to be used. On account of the differences in the tones of the emitted sparks, the two stations would be readily recognized

by the note in the telephone receiver and interference prevented as much as possible by the long wave length used. The total distance which had to be covered by this installation and for regular work was only 1,000 miles (1,600 km.); and we have no doubt now that we would not have required a ten-kilowatt station at Green River. The coming of the more sensitive audion detector has made this certain.

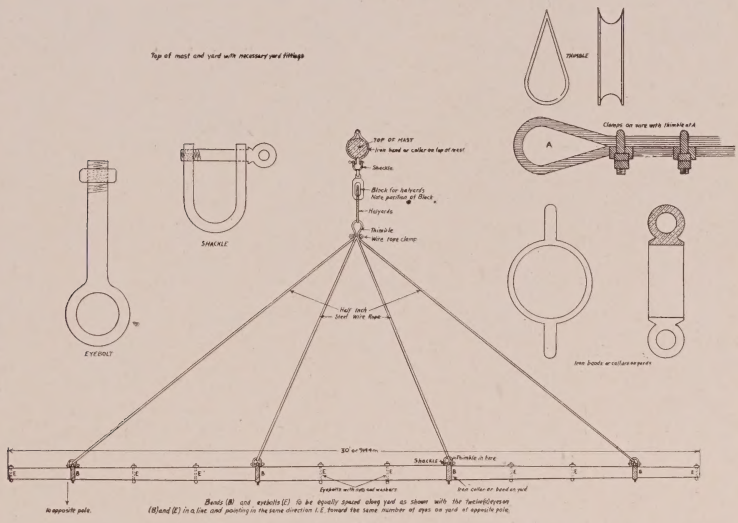
Top of mast and yard with necessary yard fittings
THIMBLE
Clamps on wire with thimble at A
A
TOP OF MAST
Iron band w collar on top of mast
Shackle
Block for halyards
Note position of Block
Halyards
Thimble
Wire rope clamp
SHACKLE
EYEBOLT
Half inch
Steel wire Rope
Iron hoods w collars on poles
30 or 9m.
Shackle
Thimble in here
Iron collar to bend on rod
Eyebolts with nut and washers
Insulators on opposite pole.
Bands (B) and eyebolts (E) to be equally spaced along yard as shown with the two (B) eyes on (B) and (E) in a line and pointing in the same direction i.e. toward the same number of eyes on yard at opposite pole.

FIGURE 12—Standard 12-wire 30-foot (9 m.) Spreader

RADIO TELEPHONE TESTS

During our experiments, we have been piling up considerable data and making thoro studies of the conditions in our section of the country. The question had come up some time before as to which system would go farthest with the least amount of energy: the arc or spark method; and the results seemed to us very clear: that for short wave lengths the spark method was best, and the arc method for long wave lengths. From the very beginning of the study of radio telegraphy, it has always seemed that the ideal instrument would be a radio telephone; and from the very beginning we hoped to be able to communicate by telegraph and telephone to moving trains. For some time, we worked on a radio telephone which seemed to be perfect so far as oscillation generation was con-

cerned. It was not till 1909, under rather critical circumstances, that Mr. Harvey Gamer and I devised a successful modulation method.

Our first radiophone was made up of a series of four arcs—water-cooled, in a hydrocarbon atmosphere and under the influence of a magnetic field. The first of these is shown in

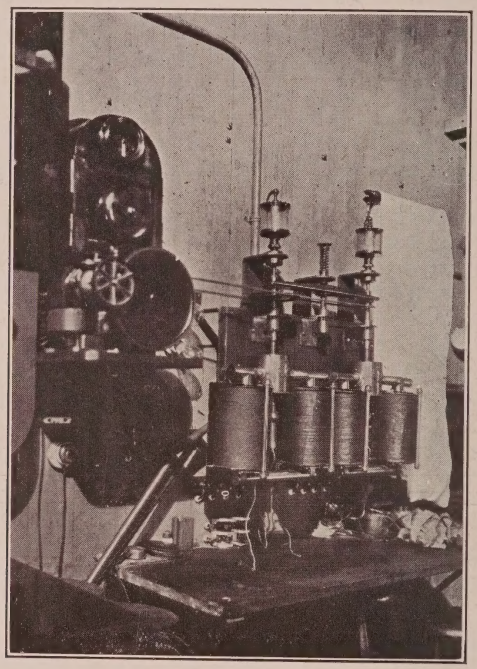

FIGURE 13—First Radiophone Arc Transmitter

Figure 13. Figure 14 illustrates the second attempt made to generate continuous oscillations by the arc method. A still later type is shown in Figure 15. In this installation the positive electrodes were made of copper, and the negative electrodes were made of some other electrical conducting material, usually carbon. The combination of a hollow metallic electrode having a chamber or cavity in its arcing end, the axial length of which was at least equal to its transverse diameter, and a negative electrode with its hemispherical end introduced within the cavity and substantially at the focal point thereof was found

useful. A diagrammatic representation is shown in Figure 16, together with our method of modulating as much energy as possible by means of the microphone.

It is well known that an arc burning in the presence of oxygen, or in an atmosphere containing oxygen, will at times

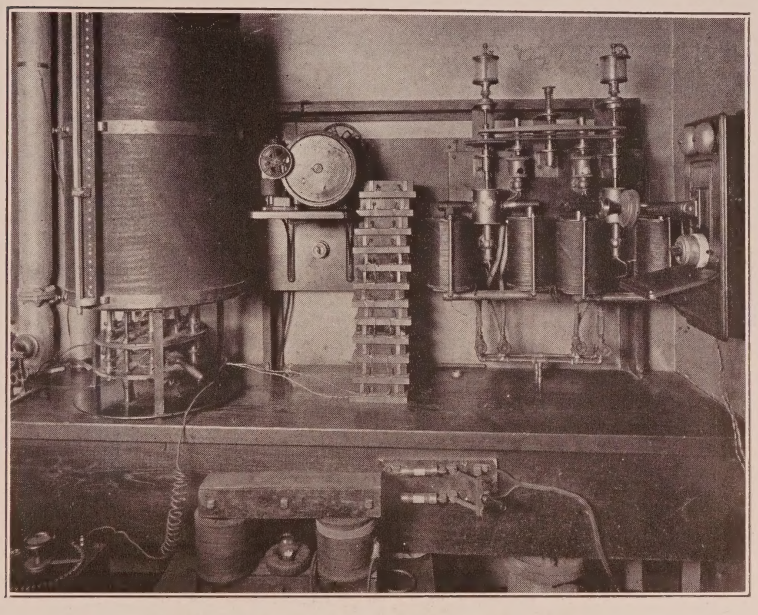

FIGURE 14—Second Radiophone Arc

hiss; and it is also known that when the hissing occurs there is a marked decrease in the difference of potential between the electrodes. This drop in potential, or any considerable variation thereof, interferes in greater or less degree with the operation of a radio transmitter in which the arc is employed to convert, or aid in converting, a direct current into an alternating current of radio frequency. Where several arcs are so employed, some or all commonly go out or cease to burn when the hissing begins. Such hissing is peculiarly detrimental when it occurs in a system of the character here described, that is, one used for speech transmission, because, in addition to its other bad effects, the hissing of the arc in great measure drowns the sound waves produced by the voice of the speaker, and precludes a clear

transmission and the certain and distinct hearing and interpretation thereof at the receiving point of the system. To prevent this hissing and to secure increased energy of the oscillations produced by an arc, the arc or arcs are enveloped in an atmosphere of hydrogen or other gas, or other means are adopted to exclude oxygen from the arc, the crater, or the vapor generated in and by the arc. While such means will give satisfactory

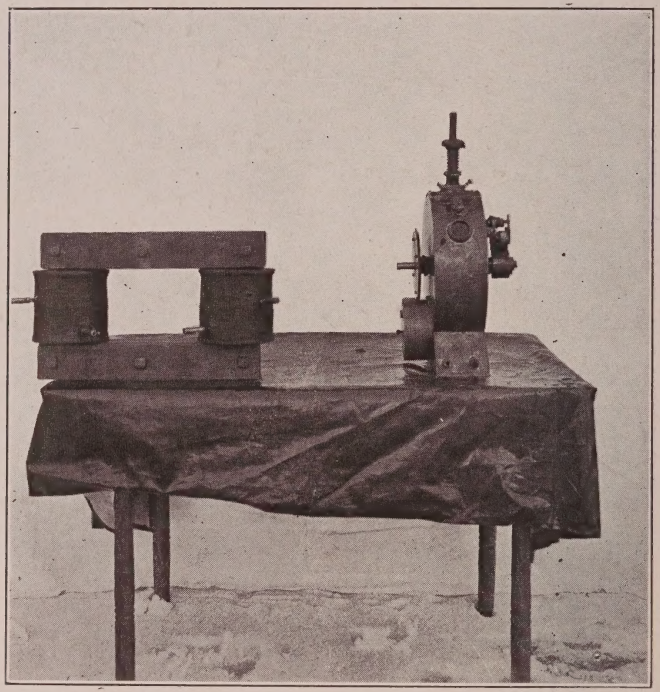

FIGURE 15—Third Radiophone Arc

results (and while we had, in a patent application, described a simple and efficient way of producing and applying such gas), we had concluded that if the positive electrode be kept cool, and the negative electrode be surrounded thereby, from its upper or arcing extremity downward to a reasonable distance, hissing of the arc may be equally well prevented, and without the necessity for any other provision or apparatus. The suppression of the hissing we believe to be due to the fact that with the positive electrode kept cool there is almost entire

absence of fusion of the electrode or of the formation of metallic globules, roughened portions or projections, depressions or pittings, which might, and in fact do, produce a variation in the length of the arc, accompanied by variation in the difference of potential between the electrodes; and to the further fact that whatever oxygen may be contained in the cup or inner cylinder of the positive electrode is speedily consumed, and the resultant or remaining gas or vapor, of whatever character it may be, rising or tending to rise by reason of its heated state,

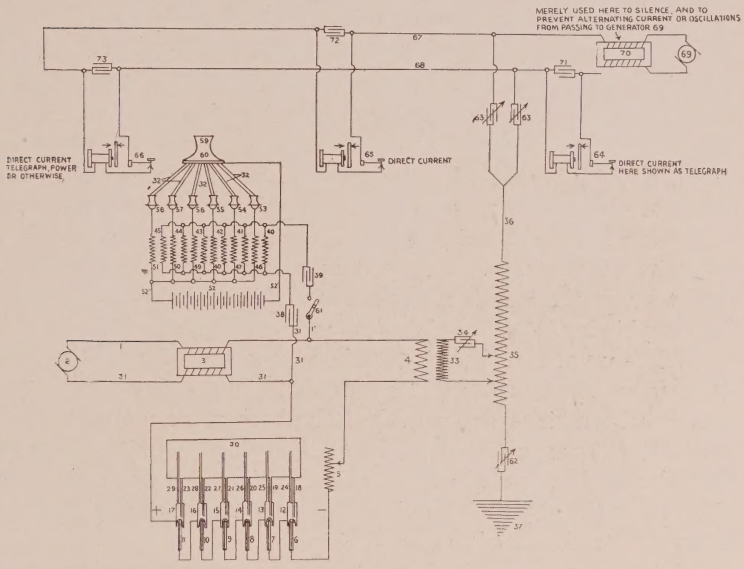
MERELY USED HERE TO SILENCE, AND TO PREVENT ALTERNATING CURRENT OR OSCILLATIONS FROM PASSING TO GENERATOR 69
DIRECT CURRENT TELEGRAPH, POWER OR OTHERWISE
DIRECT CURRENT
DIRECT CURRENT HERE SHOWN AS TELEGRAPH

FIGURE 16—Radio Telephone Transmitter Circuit

fills and occupies the entire interior of such inner cylinder or cup, and completely envelops the enclosed extremity of the negative electrode, thereby precluding the ingress of oxygen or the contact of such oxygen with the arc, the vapor thereof, or the crater. Not only is the hissing suppressed or eliminated, but with this arrangement of the electrodes, after striking the arcs the electrodes may be gradually separated, making the arcs longer and drawing more current without causing hissing thereof, provided the voltage be adequate. We also found that with the current from sources of 500 volts or more and with arcs of from one to one and one-half inches (2.5 to 3.75 cm.), and with

seven to ten amperes supply current, the results with distant reception are improved, and the electrodes can be adjusted and the consequent arcs varied without producing the hissing sound. When several arcs are formed or burning in series, and the voltage is sufficient only to maintain them, even tho the separation of the electrodes be as slight as a quarter of an inch (6 mm.) or less, it is found that if air comes in contact with the positive electrode, and the crater runs up the side thereof, hissing begins. Such an arc absorbs more than its proper proportion of the electromotive force, there is a decrease of potential in the other arcs, and they cease or go out. If there is an available surplus voltage, this action does not take place. Steady sustained oscillations are produced, and articulate speech may be clearly and distinctly transmitted and received by apparatus constructed as above set forth. The same construction and arrangement is adopted for each pair of electrodes used, and by reason of suppression of the hissing and its attendant effects, we were enabled to maintain in proper arcing condition for prolonged periods of time, a considerable number of pairs of electrodes, arranged in series as above described, and to vary the length of such arcs within wide limits, without causing hissing.

While we are on the subject of arc generators for oscillations, it may be noted in the latter arcs that the magnetic blast and gas has been done away with. The arcs work more steadily without the magnetic blast; and there is a definite value of inductance for any given capacity, which gives a maximum current in the shunt circuit. If gas is used, as the gas pressure rises the steadiness of the arcs diminish.

Altogether we made four radiophone generators of the arc type, and they worked very satisfactorily and over considerable distances. They worked very well for radio telegraphy or for any use where they could be maintained in a stationary position, but they were heavy and ungainly and required considerable attention. In fact, they required a skilled operator.

Continuing our consideration of the arc radiophone, it was found satisfactory for the continuation of our experimental work in talking to a moving train. The oscillation generator was to be placed in the baggage car of the train, and also in the station with which we intended to talk. Experiments with these arrangements were made in the shop yards and were rather satisfactory. We even combined some of our previous experiments with the electric truck, and not only controlled it by

radio, but also talked to it while in motion by the radio telephone. The intention was to use two telegraph wires made of copper or two parallel conductors thoroly insulated along the right of way, these to be used for wire telegraphy if desired; and by proper placing of condensers at stations they were also to act as long antennas.

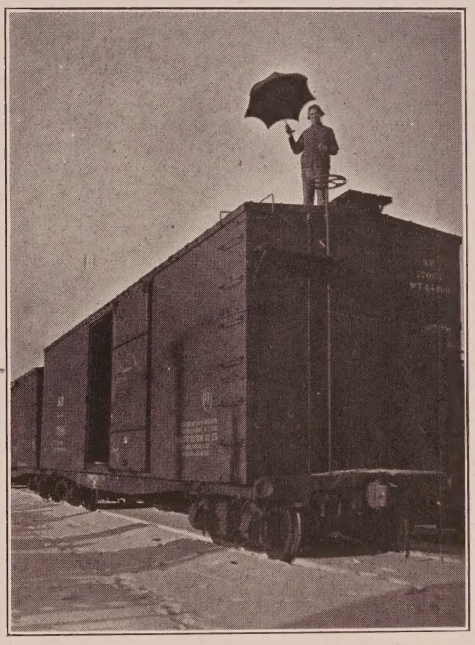

FIGURE 17—Umbrella Antenna for Radiophone Reception

Figure 17 illustrates what is literally an "umbrella antenna" for portable radiophone receiving stations. The tuning apparatus necessary for this work and the detector are placed in the upper ribs of the umbrella. (The umbrella was primarily used to convince doubting individuals of the actual radiophone transmission.) With the crude methods of tuning we had with this apparatus, we were able to talk or play a phonograph into the transmitter of the radio telephone, the speech or music being distinctly heard by the person with the umbrella three-quarters of a mile (1.2 km.) away. Transmission was, of course, possible

over much greater distances than this, but not with such crude receiving apparatus. When the radiophone transmitter was connected directly with telegraph wires properly provided with condensers to avoid the telegraph sounders and other telegraphic equipment, the voice appeared to be very distant and it was

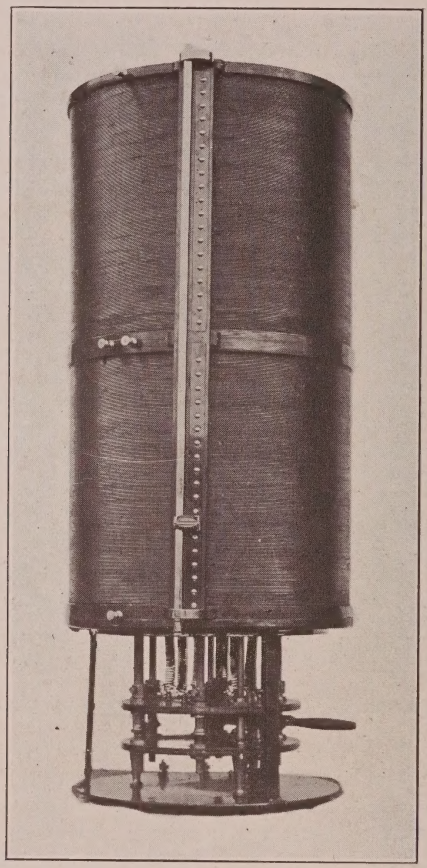

FIGURE 18—Arc and Direct Coupler for Radiophone

very difficult to recognize the inflections of the voice or to identify the speaker, altho one could recognize what was said. The voice sounded very much as it does on the transcontinental telephone. As soon as the voice was received from an antenna

not connected with the wire in any way, inflections of the voice could easily be caught and the person recognized. Our latest multiple arc direct coupler is shown in Figure 18, and the remainder of the radiophone transmitter in Figure 19.

In connection with this work, we present in Figure 20 a diagram of a train equipped with a radiophone station. The antenna is on top of the cars and is connected by couplers for the full length of the train. The coupler is shown in Figure 21.

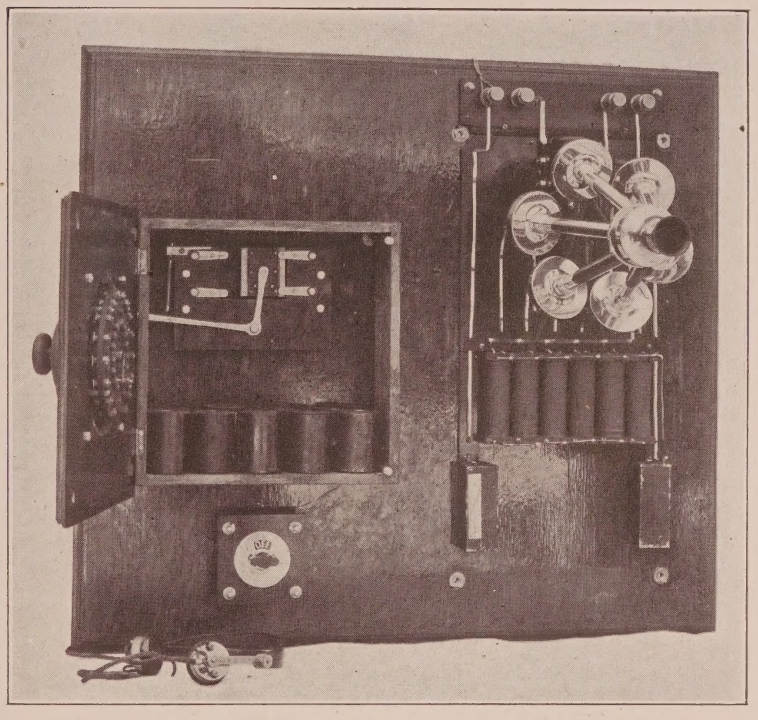

FIGURE 19—Arc Radiophone Transmitter

The train is wired for an intercommunicating set of telephones between cars. A typical station of the intercommunicating system is illustrated in Figure 22. An arrangement is here made so that persons in an observation car may talk with the baggage or dining car, or, if a train happens to be at a station, communication may be had with the city system. Figure 23

shows the experimental equipment for this system set up in the laboratory, and Figure 24 a line coupler. If, after the train had left the station, it is desired to converse with the station, this may be accomplished by connecting any one of these telephones with what would correspond to the ground wire of the antenna circuit in the baggage car. By first calling the baggage

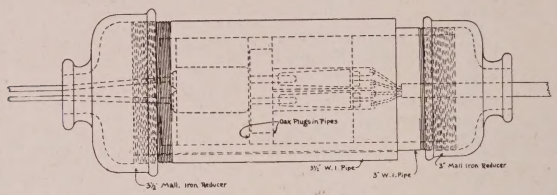

FIGURE 21—Coupler Between Cars Equipped for Radio Service

car and requesting them to provide a radiophone connection (that is, to start the oscillation generator and then cutting in the microphone on the antenna circuit), such communication could be obtained. This system worked perfectly in the shop grounds using the electric truck and several small cars which ran on the narrow gauge railway.

The next laboratory was a movable one, and a photo-

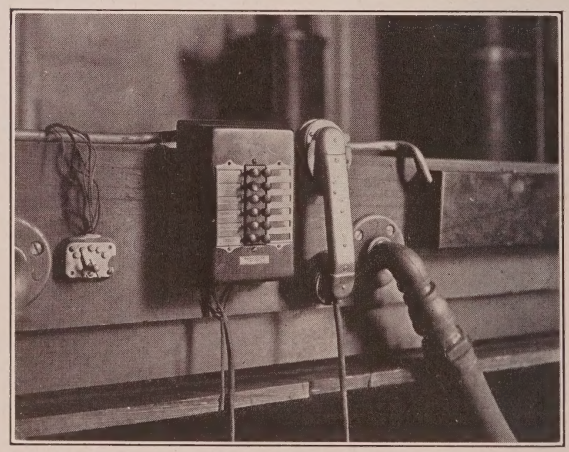

FIGURE 22—Telephone Intercommunicating Station for Wire or Radio Communication

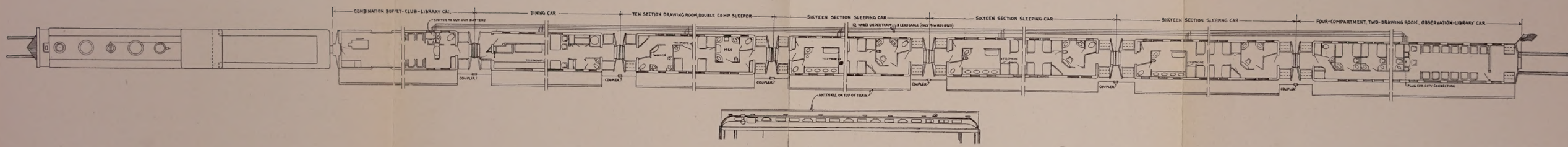

FIGURE 20—System of Train Wire and Radio Telephony

graph thereof is given in Figure 25. Car 399 was designed as a laboratory to carry on these experiments in connection with the first class trains of the railroad. The war, however, had begun; and in 1916 new men took charge of the railroad and this experimental work was temporarily discontinued.

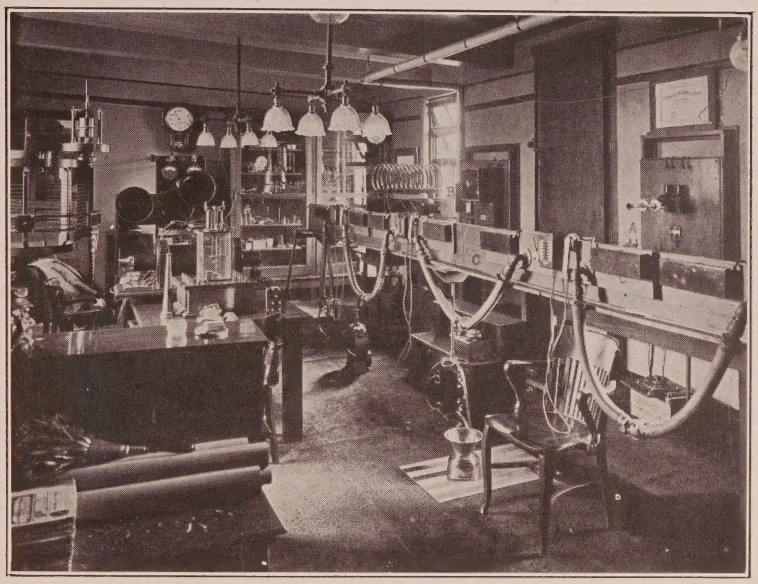

FIGURE 23—Model of Train Wire and Radio Telephone System

THE RADIO LABORATORY CAR

The radio laboratory car was made over from a diner. The kitchen and two of the refrigerators, together with the water tank and hot and cold water, were allowed to remain. The pantry was converted into an engine room (shown in Figure 26) in which we had a 40-horse-power (30 kilowatt) gasoline engine; the shelves of the pantry were used for the glass condensers, and in the roof of the car in the pantry were gasoline tanks, holding a barrel of gasoline, and refillable from the roof. The car was renumbered 399 and classified as an educational car (similarly to the air brake cars and medical examiner's cars, etc.). In the kitchen nothing was changed. A three-phase generator and switchboard, together with the gasoline engine

mentioned, were placed in the pantry, and a door cut thru from the kitchen to the pantry so that access from the body of the car could be had thru the engine room. The shelves for kitchen

FIGURE 24—Inter-Car Coupler of Wire and Radio Telephone Railroad System

utensils, etc., were left in place but soldering irons, a Wheatstone bridge, and vises and mechanical tools were also added so that

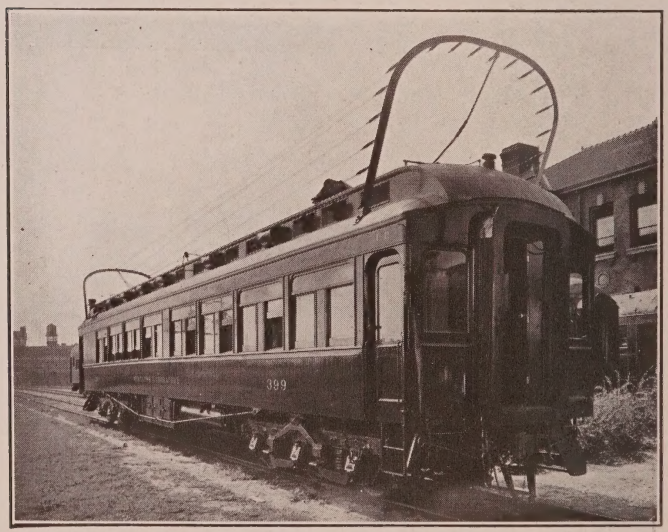

FIGURE 25—Railroad Radio Laboratory, Showing Antenna and Car Couplers

the kitchen could be turned into a work shop when desired. Curtains were placed so that the main portion of the car could be utilized for sleeping purposes, the cots being placed over the toilet and other convenient places at the end of the car under the roof when not in use. Where the sideboard used to be, the

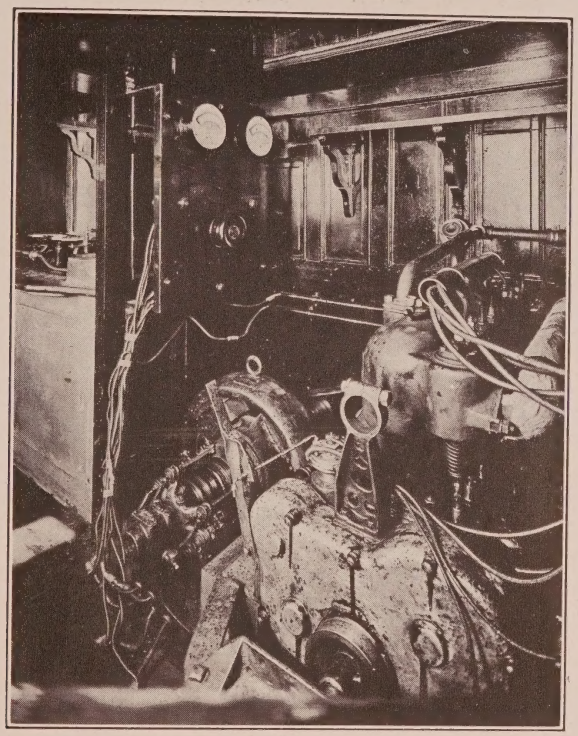

FIGURE 26—Engine Room of Radio Laboratory Car During Installation

coil of the direct coupler was placed and an opening made thru roof for the antenna. The car was 67 feet 9 inches (20.6 m.) over all and the antenna contained twenty-one wires. The highest wires on the frame were connected, forming one antenna; and the other wires were so connected that we had three antennas available which could be switched into one or connected in the car in any manner we desired. On the platform under the dome at the kitchen end of the car, it was intended to place a

"Komet" mast. This is a sectional mast made in Germany, which is elevated by means of a crank and shaft. When telescoped, it occupied a space 6 inches (15 cm.) in diameter and 8 feet (2.4 m.) high. When extended its height was 82 feet (25 m.). This was provided in case we wished to use the car as a telegraph office and desired to transmit over greater distances than we could with the antenna on the car. This type of mast is shown in Figure 27.

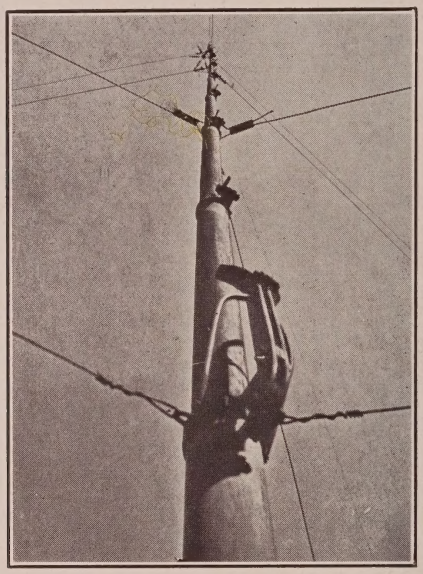

FIGURE 27—"Komet" Mast

It struck us at the time how singularly well adapted this laboratory was for portable long range communication purposes, since it contained both electric light and gas; and, if necessary, two other cars could be lighted from the power plant on the car (which included a three-phase generator). It would have made an ideal headquarters car for the receiving and dispatching of telegraphic work—both wire and radio. The interior view of this car is given in Figure 28. At the forward end of the car was the operator, and to the right of him was the transformer and rotary spark gap. As was stated above, the antenna wire left the car at about its middle. The ground wires resembled

a letter "H" and were fastened to the trucks underneath the car and to the truck boxes, on the inner lid of each of which was a spring ending in a cone which fitted into the conical depression

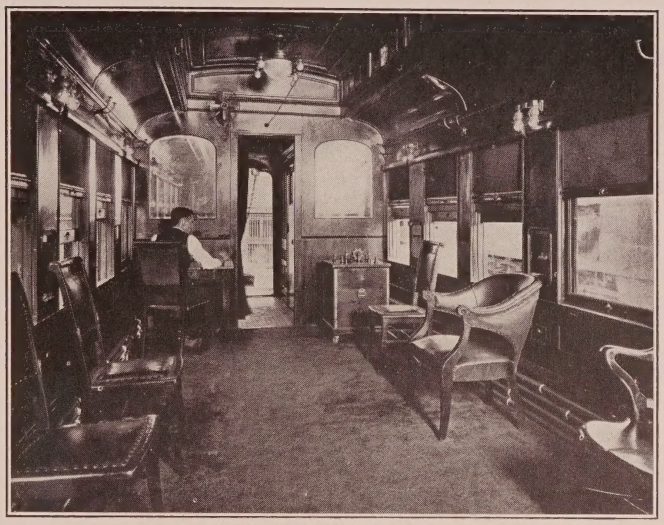

FIGURE 28—Operator on Duty in Radio Laboratory Car

in the end of the axle, so that when the box was closed tightly we had a friction ground on the axle of the car.

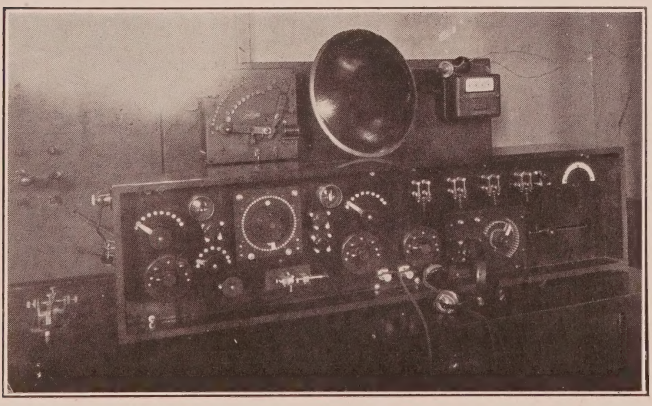

FIGURE 29—Receiving Station at Union Pacific Headquarters

On taking measurements with the Wheatstone bridge it was found that the resistance between the truck and the rail and between the axle and the rail was on an average as follows:—between truck and rail —0.365 ohm, between axle and rail —0.26 ohm.

Of course the greater the number of connections which the ground wire has to the different axles, the less will be the resistance between the car and the ground, providing we do not increase the amount of wire resistance.

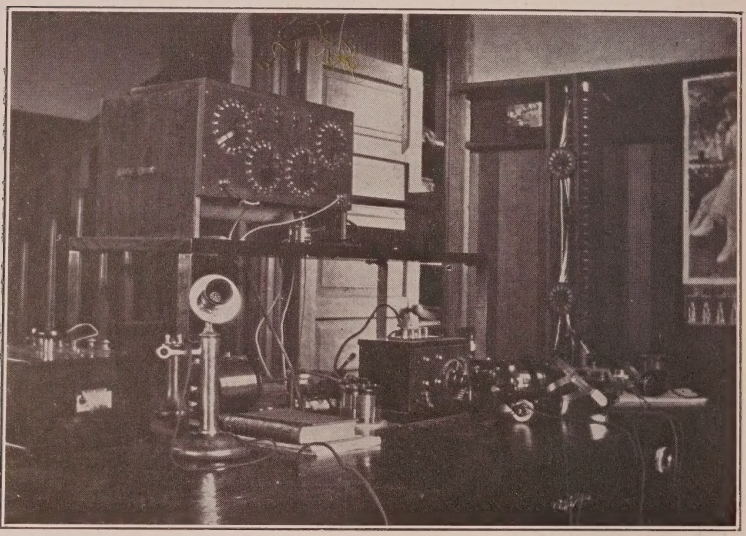

FIGURE 30—Receiving Set, Including Coaxial Cylindrical Coupler, and Loading Coil

LARGE CYLINDRICAL COUPLER OF COAXIAL CONSTRUCTION

The first operating room at Union Pacific headquarters is illustrated in Figure 29. A more recent receiver is shown in Figure 30. The antenna used therewith is a five-wire one, wires 2.5 feet (75 cm.) apart, 80 feet (25 m.) long and seventy-five feet (22 m.) above ground and of the "L" type. The couplers, detectors, and inductance are all mounted on one table. At all times, day or night (whenever they are working), we are able to copy the following stations. While there is nothing unusually extraordinary about this reception, it is regarded as

satisfactory, because, until recently, we used an umbrella type antenna supported on a field mast.

"K I E"	Honolulu	"N A A"	Arlington
"N P L"	San Francisco	"N A D"	Boston
"W S L"	Sayville	"W I I"	Belmar
"W G G"	Tuckerton	"W S E"	Seagate
	"N A T" New Orleans		

The wiring diagram of the receiver is given in Figure 31.

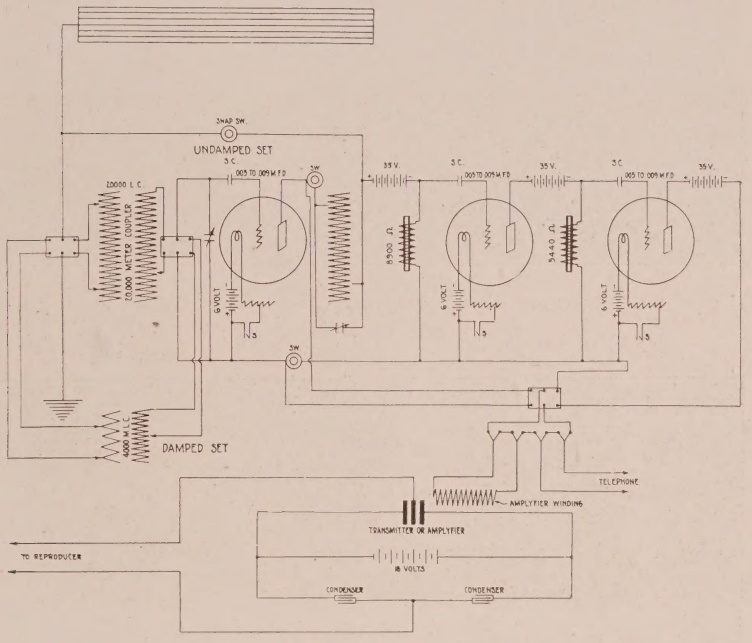

FIGURE 31—Receiving Set

RECORDING RECEIVED SIGNALS

Early in these experiments, we tried to copy and preserve radio messages on the phonograph. Figure 32 shows a telegraphone recorder while Figure 33 shows equipment adapted to the Columbia dictaphone. With these, however, we did not entirely succeed because we did not have a receiver of constant adjustment. At the present time, we are having fair success using a powerful amplifying relay shown in relay Figures 34 and 35. This is really a powerful telephone transmitter with associated circuits of special design.

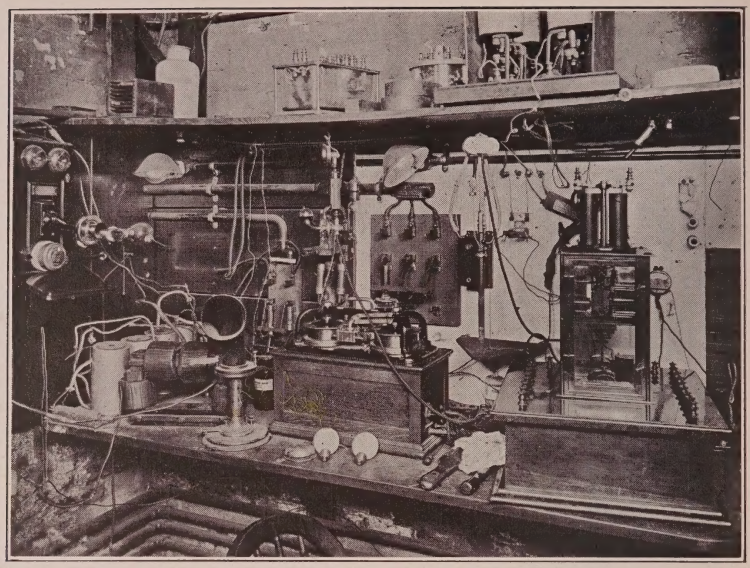

FIGURE 32—Telegraphone Recorder of Radio Signals

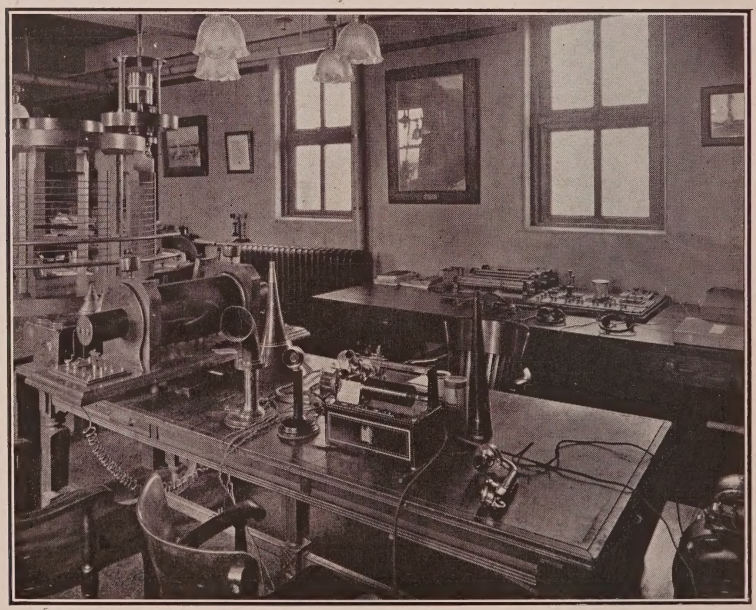

FIGURE 33—Dictaphone Recorder for Radio Signals

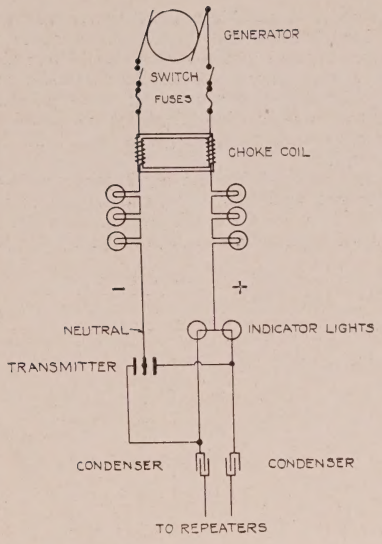

FIGURE 34—Equipment Associated with Amplifier

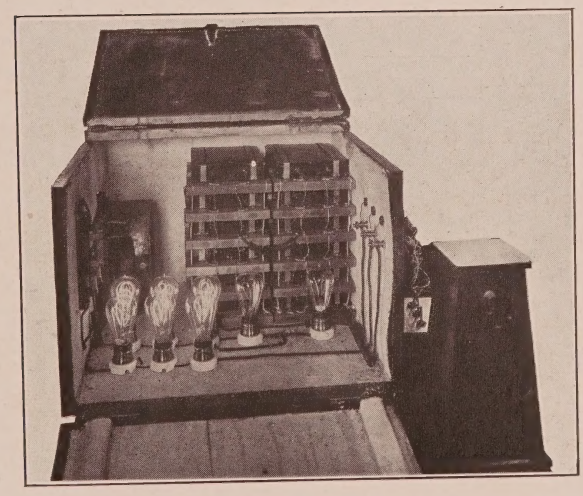

FIGURE 35—Amplifying Relay Equipment

SUMMARY: The radiotelegraphic researches carried on under the auspices of the Union Pacific Railroad are described. A radio "danger" signaling system was first worked; and while operative, did not give the extreme reliability required by such systems. A radio controlled car is then described.

A series of experiments with arc radiophone equipment are considered. Their applications to inter-car wire telephone communication and train-to-station radiophone communication are given in detail. The necessary fixed stations are also described.

The experimental radiotelegraphic car laboratory is then described, together with the antennas, ground, engine, and transmitter thereof.

Finally, receiving sets and a telephone relay amplifier (intended to facilitate telegraphone or dictaphone recording of signals) are considered.

DISCUSSION

George B. Joslin: I recall an experience which I had similar to that of several of the gentlemen present, which illustrates the general opposition with which old railroad employees who had always been accustomed to Morse methods of communication, met an early attempt to experiment along the line of telephonic train dispatching. It was at the time I was in charge of the installation of a railway composite telephone circuit between ———— and ————. A wire was selected for the experiment, supposed to be the best between the two points, and at each intermediate station into which this wire looped for telegraph purposes, a condenser was supposed to be bridged across the pin board terminals for the purpose of shunting the telegraph relay against higher frequency telephonic currents. In most cases this wire entered railroad switching and signaling towers, over which presided an old railway employee thoroly familiar with Morse, and bitterly opposed to any innovation which would tend, if it succeeded, to relieve him of his job. These men were of the unanimous opinion that telephonic train dispatching was doomed to failure as it would be impossible to transmit orders by telephone and have them thoroly understood and executed, as, according to them, there was a tendency to take telephone messages in one ear and out of the other. They said instructions communicated in this manner could never stick in a man's mind, but orders communicated by telegraph and as transmitted by a telegraph sounder were literally hammered into the conscience of the man at the receiving end in a manner that he could not forget. We had a howler device for receiving high frequency signaling currents which would not affect or disturb the operation of the telegraph relays on the line; it was what is known to-day as a loud-speaking telephone or receiver in the form of a horn, operated by a diafram mounted on the wall above the telephone instrument. It was loud speaking in that it spoke Morse as well as high frequency notes, so that altho there was telephone secrecy on the telegraph line there was no telegraph secrecy at stations where the composite equipment looped in. From a telephone standpoint, however, our experimental wire was very unsatisfactory as it took up inductively all Morse impulses or rather a composite conglomeration from the neighboring wires, which ran parallel to it, along the pole line a distance of over 200 miles (320 kw.).

The telephonic apparatus to which I refer, was a device tried out in New England about twelve years ago and called a "Railway Composite." It was designed to utilize existing telegraph wires for the electrical transmission of speech without interfering with the telegraphic functions of the wire. My experience with a single untransposed wire—a wire that took the same identical pin on the same particular cross-arm of the telegraph pole line over a distance of 200 miles—was similar to some mentioned. Under this condition, we could hardly avoid getting everything on our wire, by induction, that took place on its neighboring wires thruout this distance, and it occurred to me that the trouble mentioned in early experiments may have been of the same nature, and due to the fact that the line was not transposed or otherwise prepared for telephonic transmission of speech.

FURTHER DISCUSSION ON "OSCILLATING AUDION CIRCUITS" BY L. A. HAZELTINE*

By

August Hund

Professor Hazeltine's paper in the April, 1918, issue of the Proceedings of The Institute of Radio Engineers is certainly of interest to many radio engineers, since it gives the explanation for almost any oscillator arrangement of the three-element type of hot cathode apparatus, using primary emission of electrons. His treatment by means of the loss method has great inherent advantages, since for certain types of coupled systems it may avoid equations of higher degree. Altho the determinant solution at the end of his paper is very broad, it seems worth while to give here a solution which the writer developed several years ago in connection with the oscillating pliotron. The method employed makes use of the generalized symbolic method and is illustrated by the most common arrangement such as indicated in Figure 1, the nomenclature being the same as in Professor Hazeltine's paper. The procedure gives

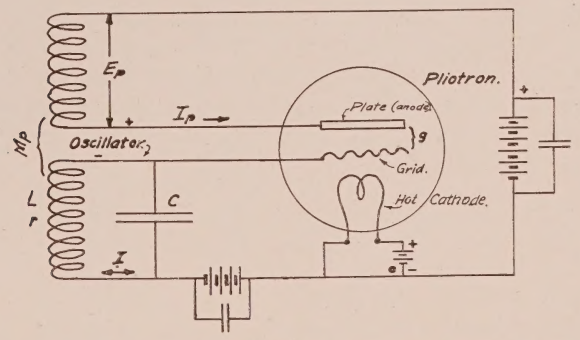

Figure 1

a ready means for determining directly the freuuency of oscillation as well as the relative magnitude of the mutual conducts

* Proceedings of The Institute of Radio Engineers, April, 1918.

ance, g, mutual inductance, M_P, capacity, C, and ohmic resistance, r, simultaneously indicating how plate and oscillator (grid—in this special case) are to be connected. The solution is:

$$I\left[r+nL+\frac{1}{nC}\right]+I_P\, n\, M_P=0$$

combined with the relation

$$\begin{aligned} I_P &= E_G \cdot g \\ &= \frac{I}{nC}g \end{aligned}$$

results in

$$n^2L+n\left[r+\frac{M_P}{C}g\right]+\frac{1}{C}-0$$

which for the oscillatory case leads to the two complex and conjugate angular velocities

$$\begin{aligned} n &= a \pm j\,\omega \\ &= -\frac{1}{2L}\left[r+\frac{M_P}{C}g\right] \pm j\sqrt{\frac{1}{CL}-\left[\frac{1}{2L}\left(r+\frac{M_P}{C}g\right)\right]^2} \end{aligned}$$

For sinusoidal oscillations, $a=0$, that is,

$$g^{mhos}=\frac{C^F \cdot r^\Omega}{[-M_P]^H}$$

and

$$f^{-sec}=\frac{1}{2\pi\sqrt{C^F L^H}}$$

The negative sign belongs necessarily to M_P and indicates that the plate coil must at any instant be of opposite polarity to the grid (oscillator) coil, both being referred to the negative end of the hot cathode.

ON THE INTERPRETATION OF EARLY TRANSMISSION EXPERIMENTS BY COMMANDANT TISSOT AND THEIR APPLICATION TO THE VERIFICATION OF A FUNDAMENTAL FORMULA IN RADIO TRANSMISSION*

By

Leon Bouthillon

(Engineer in Charge of the Radio Telegraphic Service of the Postal and Telegraph Department of France)

For radio transmission with damped oscillations over flat and perfectly conducting ground, with the air regarded as a loss-free dielectric, and for distances greater than several times the wave length, the following expression for the current at the base of the receiving antenna may be deduced theroetically:

$$I_r = 377 \frac{I_s}{R} \cdot \frac{h_1 h_2}{\lambda d} \cdot \frac{1}{\sqrt{1+\frac{\delta_1}{\delta_2}}}$$

where I_r is the current at the base of the receiving antenna;

I_s the current at the base of the transmitting antenna;

R the total resistance of the receiving antenna, including the radiation resistance;

h_1 and h_2 the effective heights of the two antennas;

d the distance between the antennas;

λ the wave length; and

δ_1 and δ_2 the decrements of the sending and receiving antennas respectively.

In this equation, the lengths are expressed in centimeters (0.4 inch), the currents in amperes, and the resistances in ohms. Even if the upper layers of the atmosphere are regarded as an imperfect dielectric, the formula given is applicable to short-range transmission over the ocean.

*Received by the Editor, April 17, 1917. Translated from the French by the Editor.

The proportionality between the current and the effective heights has been verified by the experiments of W. Duddell, J. E. Taylor, L. W. Austin, and others; while the proportionality between received and transmitting current and the influence of the resistance has also been shown to be correct.

The experiments carried on by J. E. Taylor and by Commandant Tissot have similarly shown that, for small distances, the current at the foot of the receiving antenna is in inverse ratio to the distance between the stations. The value of the numerical factor entering into the expression has not, up to the present, been determined experimentally with sufficient exactitude. Barkhausen showed that, on the basis of certain plausible hypotheses, the experiments of L. W. Austin led to the value 377 for this factor. On the other hand, the experiments of W. Duddell and J. E. Taylor are too incomplete to permit deducting this factor from them.

It seems interesting to show that the experiments of Commandant Tissot were of such nature as to constitute a valuable contribution to the study of this question. These experiments, tho carried on at an early date, were so carefully performed and the deductions therefrom were published so precisely[1] that it is possible to calculate the desired numerical factor from them with a close degree of approximation.

The transmitting and receiving antennas consisted each of a single vertical wire 50 meters (162 feet) high and 0.4 centimeter (0.16 inch) in diameter. The transmitting antenna was on board ship, and the transmission was direct.

The current measured at the base of the transmitting antenna was $I_s = 0.95$ ampere. The receiving antenna was on land. A bolometer of resistance $\rho = 17.5$ ohms was inserted at the foot of the antenna. The received current at this point was $I_r = 1.5\ (10)^{-3}$ ampere. The wave length was 210 meters. The distance d between the stations was 1,700 m. (somewhat over a mile). The decrement at the transmitter was $\delta_1 = 0.24$. The measured capacity of the antenna was $C = 300$ cm. (E. S. U.) or 0.00033 microfarad. We shall first calculate the quantities entering into the formula for I_r.

The resistance R of the receiving antenna consists of an ohmic resistance which was almost entirely that of the bolometer, namely $\rho = 17.5$ ohms, and of the radiation resistance R_Σ.

[1] In the publication "Sur la resonance des systemes d'antennes," Paris 1905.

The receiving antenna was exactly similar to the transmitting antenna, and, since the transmission was direct, the current distribution was sinusoidal in both antennas and the radiation resistance was given by the expression

$$R_{\Sigma} = 160\,\pi^2 \left(\frac{2}{\pi} \cdot \frac{h}{\lambda}\right)^2$$

h being the actual height of the antennas. In the present case:

$$R = 160\,\pi^2 \left(\frac{2}{\pi} \cdot \frac{50}{210}\right)^2 = 36.5 \text{ ohms.}$$

From this we get $R = R_{\Sigma} + \rho = 36.5 + 17.5 = 54$ ohms. Since the current is sinusoidal, the effective heights of the antennas, h_1 and h_2, are

$$h_1 = h_2 = \frac{2}{\pi} h = \frac{2}{\pi} 50 \text{ meters.}$$

We must still calculate the damping of the receiving antenna. This is given by the equation

$$\delta_2 = \frac{R}{2\,n\,L} \cdot \frac{\pi}{2}$$

where n is the frequency and L the audio frequency inductance of the system. (The equivalent inductance with sinusoidal distribution is $\frac{2}{\pi} L$.) The inductance L can be deduced from the experimentally determined value of C, namely 300 cm., by the equation $C\,L = h^2$, (C, L, and h being expressed in centimeters), assuming a sinusoidal current distribution along the antenna. Thus we obtain:

$$L = \frac{(5\ (10)^3)^2}{300} = 0.833(10)^5 \text{ cm. or}$$

$$L = 0.833(10)^{-4} \text{ henry.}$$

Also

$$n = \frac{3(10)^{10}}{\lambda} = \frac{3(10)^{10}}{210(10)^2} = \frac{(10)^6}{7}.$$

If, in the expression for δ_2, we replace, R, L, and n by their values, we obtain:

$$\delta_2 = \frac{54 \cdot 0.7 \cdot \pi}{2(10)^6 \cdot 0.833(10)^{-4} \cdot 2} = 0.356.$$

Finally we obtain the value of the numerical coefficient in the formula:

$$k=\frac{I_r}{I_s}\cdot\frac{R\lambda d\sqrt{1+\frac{\delta_1}{\delta_2}}}{h_1 h_2},$$

$$k=\frac{1.5(10)^{-3}}{0.95}\cdot\frac{54\cdot 210\cdot 1700\sqrt{1+\frac{0.24}{0.356}}}{\left(\frac{2}{\pi}50\right)^2},\ \text{or}$$

$$k=390.$$

This value is in perfect agreement, as far as can be expected from the degree of precision of the experiments, with the theoretical value of the constant, namely 377.

Thus the experiments of Commandant Tissot may be considered as verifying the important formula which is at the basis of all electromagnetic wave transmission much more satisfactorily than those made before.

SUMMARY: Some early experiments by Commandant Tissot (1905) are used to calculate the value of the constant entering into the usual transmission formula (neglecting the transmission absorption term). The value of the numerical constant in the formula as determined from the experiments agrees well with the theoretical value.

DISCUSSION

Oscar C. Roos (communicated)*: In connection with M. Bouthillon's paper, it may be interesting to call attention to the fact that the current distribution might not be sinusoidal in the antenna vibrating at 210 meters, which is a longer wave-length than its fundamental of 200 meters under the classical theory. However, according to Conrad and Pierce 4.2 times the height gives the fundamental wave-length which in this case is exactly 210 meters. These considerations affect the form-factor and the value of k in the Austin-Cohen formula.

The experiments of Tissot on current distribution are very interesting, especially on the receiver side of the problem. It is entirely possible that the proper form-factor has not been deduced by M. Bouthillon for reasons which follow, and hence the decrement of the receiving antenna $\frac{\pi}{4} \cdot \frac{R_o}{L_o n}$ will change in direct proportion to the error; as R varies as the square of the form-factor and L inversely as the form-factor. Hence, in the final expression for k which is

$$\frac{I_r}{I_s} \cdot R_o \lambda d \sqrt{\frac{1+\delta_1}{\delta_2}},$$

the radiation term 36.5 ohms (see Zenneck's "Wireless Telegraphy," page 40) in R might be corrected in the ratio $\frac{73.2}{80}$; i. e., it may be taken as 33.4 ohms, and the total R would then be 33.4+17.5 or 52 ohms closely instead of 54. Now the ratio $\frac{52}{54}$ applied to the factor $k=390$ deduced in the paper brings it to 369 which is in error by 8 parts instead of 13 out of 377.

Taking into account the same ratio of change in δ_2, we must apply a correction-factor to the radical when evaluated, of $\frac{1.318}{1.293}$, or to the value $k=369$ above. This, when applied, gives $k=376+$, which is remarkably close to the theoretical value, 377, in fact, too close—there must be other disturbing factors.

Now, if it seems advisable to modify the corrective factors introduced above, there is still the residual source of doubtful receiver form-factor to fall back upon. The current distribution in a receiving antenna vibrating harmonically is not, in general, sinusoidal. This is due to the fact that the differential

* Received June 14, 1917, by the Editor.

equations when correctly based on the e m f. induced per unit length of the receiver-antenna, contain a quadratic plus a circular (or hyperbolic) function of the frequency, of opposite signs. The sender solution contains only the latter types of function, by way of contrast.

Consider a receiver-wire vibrating at its fundamental with a resistance R_o in series to earth. The current in R_o is C_o and

$$C_o = \frac{e\,v}{R_o\,n}$$

where v = velocity of light in cm. per second,
n = vector velocity,
e = e m f. per cm.,
R_o = resistance in $\frac{\text{cm.}}{\text{sec.}}$.

The current C_x at *any* point, x cm. distant from the base of the receiver antenna or the current distribution, under the same circumstances, is given by

$$C_x = \frac{e\,i}{L\,n}\left[1 - \left\{\frac{R_o - L\,v\,i}{R_o} \cdot \cos\frac{n\,x}{v} - \sin\frac{n\,x}{v}\right\}\right] \qquad (1)$$

In this equation, when $x = \frac{\lambda}{4} = a$, at the top of the antenna, $C_x = 0$; and when $x = 0$, $C_o = \frac{e\,v\,i}{R_o n}$ as above, at base of antenna.

This distribution-curve is a sinusoidal curve the zero point or antinode of which is displaced downward from the top of the antenna—(its normal position in the *sender* vibrating at its fundamental)—by a distance $(a - x_o)$ where

$$x_o = \frac{v}{n}\tan^{-1}\sqrt{\frac{R_o^2 + L^2 v^2}{R_o}} \qquad (2)$$

It is important to note, in passing, that L is the specific inductance per unit length of the antenna and is *not* constant along its length; hence it should be replaced by an empirical value or the calculated average value, as was done in 1905 by the writer using Heaviside's rational current element.

This receiver current distribution-curve has its geometrical node displaced away from the *axis* of abcissas by a value equal to $\frac{e}{L_m}$; because the receiver current curve has a point of inflection here.

This unusual current curve has been checked by Tissot in his bolometer measurements and was evaluated by the writer in 1907 from the differential equations appearing in the "Electrical

Review" of October 15, 1904, in an article by Mr. John Stone Stone, and by the latter independently in 1908 before the Society of Wireless Telegraph Engineers,* in Boston.

Figure 1 shows the general outline of the current distribution-curve at the fundamental with only resistance in the base of antenna. The potential distribution is the first derivative of the current distribution. The greater the surge resistance $L\,v$ is, relatively to the receiving resistance R_o—which includes the resistance of re-radiation—the higher does the point of inflection climb on the curve toward the top of the antenna and the closer becomes the resemblance between the sending and receiving distribution curves.

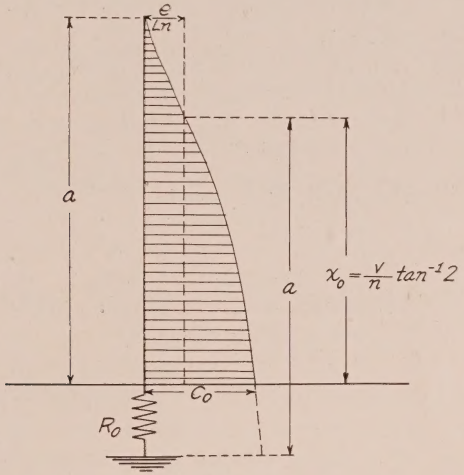

FIGURE 1

Let $L^2 v^2 = 3 R_o^2$, then $x_o = tan^{-1} 2$ and from equation (2), the point of inflection x_o is about $\frac{2}{3}$ of the way to the top of the antenna. The form-factor is lower than in a transmitter, other things being equal. The interesting question arises as to the relative currents with the same voltage at the base of two antennas, receiver and sender, respectively.

$$C_o = \frac{e\,\lambda}{R_o\,2\,\pi} \text{ at base of receiver,} = \frac{2\,a\,e}{\pi\,R_o} \qquad (3)$$

* One of the societies which combined to form THE INSTITUTE OF RADIO ENGINEERS.

Here $a\,e$ is the potential above ground of the base of the antenna or the top of the receiving equivalent resistance. In a transmitter, at the fundamental, however, $C_o = \frac{E}{R_o} = \frac{a\,e}{R_o}$, hence the current at the base of the receiver under these conditions is $\frac{2}{\pi}$ of the value it would have, other things being equal, as a transmitter.

The final general expression for receiver antenna current-distribution is given below:

Let K be a lumped reactance at the base of the antenna. Then in vector notation $Z_o = R_o + K_o$.

Let $p = n\,j = n\sqrt{-1}$, a differential operator for harmonic functions.

a = antenna height in cm.,

n = vector velocity,

$v = 3 \times 10^{10}$ cm. per sec. = velocity of light,

L = average specific inductance of antenna,

$$C_x = \frac{e}{L\,p}\left[1 - \frac{p}{v}\left\{\frac{\frac{v}{p} + \frac{Z_o}{L\,p}\sinh\frac{p\,a}{v}}{\cosh\frac{p\,a}{v} + \frac{Z_o}{L\,v}\sinh\frac{p\,a}{v}} \cdot \cosh\frac{p\,x}{v} + \frac{1 - \cosh\frac{p\,a}{v}}{\frac{L\,p}{Z_o}\cosh\frac{p\,a}{v} + \frac{p}{v}\sinh\frac{p\,a}{v}} \cdot \sinh\frac{p\,x}{v}\right\}\right] \qquad (4)$$

This is the solution of Stone's differential equation, given in 1904, for all frequencies and distances on antenna, and it shows that a receiver can vibrate at the octave, which a transmitter can not do. Neither can vibrate when $\cosh\frac{p\,a}{v} = +1$.

When the antenna resistance at the fundamental is large compared to the average surge resistance, $L\,v$, then the point of inflection is half-way down the antenna practically, and theoretically never gets more than half-way down, since $\frac{v}{n}\tan^{-1}1 = \frac{\lambda}{8} = \frac{a}{2}$.

In conclusion, it is of interest to note that while a transmitting Marconi vertical antenna can not vibrate at any multiples whatever of the octave of the fundamental, a receiver *can* vibrate at the octave and all odd multiples of same, i. e., whenever $\cos\frac{n\,a}{v} = \pi,\ 3\,\pi,\ 5\,\pi$, etc.

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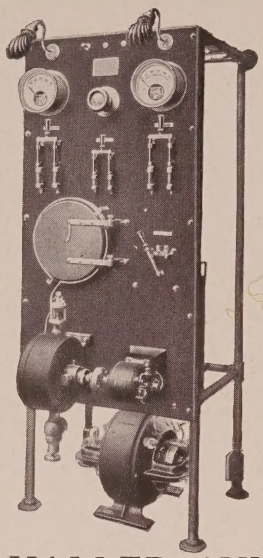

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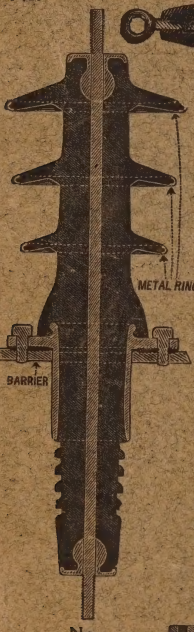

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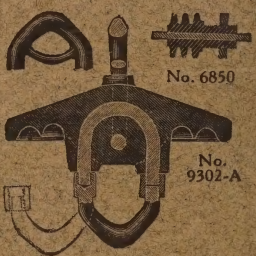

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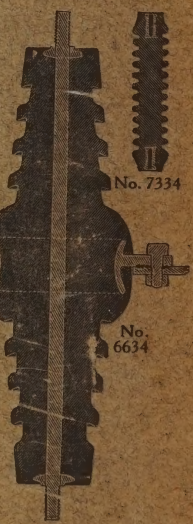

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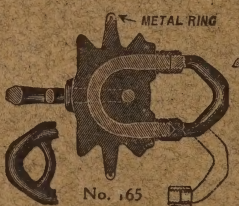

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